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क्रिस्टलीय सिलिकॉन प्रकाशवोल्टीय (पी वी) ऐरे — I-V अभिलक्षणों का ऑन-साइट मापन

Indian Standard

CRYSTALLINE SILICON PHOTOVOLTAIC (PV) ARRAY — ON-SITE MEASUREMENT OF I-V CHARACTERISTICS

ICS 27.160

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NEW DELHI 110002

February 2010

Price Group 4

Solar Photovoltaic Energy Systems Sectional Committee, ETD 26

NATIONAL FOREWORD

This Indian Standard which is identical with IEC 61829 : 1995 'Crystalline silicon photovoltaic (PV) array — On-site measurement of I-V characteristics' issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on the recommendation of the Solar Photovoltaic Energy Systems Sectional Committee and approval of the Electrotechnical Division Council.

The text of the IEC Standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'.

b) Comma (,) has been used as a decimal marker in the International Standard while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

In this adopted standard, reference appears to certain International Standards for which Indian Standards also exist. The corresponding Indian Standards which are to be substituted in their respective places are listed below along with their degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
IEC 60891 : 1987 Procedures for temperature and irradiance corrections to measured I-V characteristics of crystalline silicon photovoltaic devices	IS 12763 : 1969 Procedures for temperature and irradiance corrections to measured I-V characteristics of crystalline silicon photovoltaic devices	
IEC 60904-1 : 1987[1] Photovoltaic devices — Part 1 Measurements of photovoltaic current-voltage characteristics	IS 12762 (Part 1) : 2010 Photovoltaic devices: Part 1 Measurement of photovoltaic current voltage characteristics (*first revision*)	Technically Equivalent
IEC 60904-2 : 1969 Photovoltaic devices — Part 2: Requirements for reference solar cells	IS 12762 (Part 2) : 1993 Photovoltaic devices: Part 2 Requirements for reference solar cells	Identical
IEC 60904-3 : 1989 Photovoltaic devices — Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data	IS 12762 (Part 3) : 1996 Photovoltaic devices: Part 3 Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data	
IEC QC 001002 : 1966[2] Rules of procedure of the IEC quality assessment system for electronic components (IECQ)	IS QC 001002 (All parts) IEC quality assessment system for electronic components (IECQ) — Rules of procedure	Technically Equivalent

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[1] Since revised in 2006.

[2] Since revised in 1998 in three parts.

(*Continued on third cover*)

Indian Standard

CRYSTALLINE SILICON PHOTOVOLTAIC (PV) ARRAY — ON-SITE MEASUREMENT OF I-V CHARACTERISTICS

1 Scope and object

This International Standard describes procedures for on-site measurement of crystalline silicon photovoltaic (PV) array characteristics and for extrapolating these data to Standard Test Conditions (STC) or other selected temperatures and irradiance values.

Measurements of PV array I-V characteristics under actual on-site conditions and their extrapolation to Acceptance Test Conditions (ATC) can provide (see annex A and QC 001002):

- data on power rating;
- verification of installed array power performance relative to design specifications;
- detection of possible differences between on-site module characteristics and laboratory or factory measurements;
- detection of possible performance degradation of modules and arrays with respect to on-site initial data.

For a particular module on-site measurements extrapolated to Standard Test Conditions (STC) can be directly compared with results previously obtained in laboratory or factory for that module, provided that in both measurements the reference devices have the same spectral and spatial response as described in the relevant IEC 904.

Data from on-site array measurements contain diode, cable and mismatch losses. Therefore, they are not directly comparable to the sum of the respective module data.

If a PV array is formed with sub-arrays of different tilt, orientation, technology or electrical configuration, the procedure described here will be applied to each unique PV sub-array.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 891: 1987, *Procedures for temperature and irradiance corrections to measured I-V characteristics of crystalline silicon photovoltaic devices*
Amendment 1 (1992)

IEC 904-1: 1987. *Photovol/aie devices - Pan t: Measurements of photovottstc current-voltage charactaristles*

IEC 904-2: 1989. *Ph%val/alc devices - Pan* 2: *Raquirements for reference solar cells*

IEC 904-3: 1989. *Photovoltaic devicas - Pan* 3: *measurements principles for tarrastrial photovoltaic (PV) solar devices with reference spectral iuadiaoce data*

IEC 904-6: 1994. *Ph%val/alc devices - Pan* 6: *Requirements for refrence solar modules*

ac 001002: 1986. *Rulas of Procedure of the IEC Ouality Assassman/ System for Electronic componem» (IECQ)*
Amendment 1 (1992)

3 MeBsurement procedures (methods A and B)

Two acceptable *on-site* measurement procedures are presented here. 80th methods use the procedures given In IEC 891 for temperature and irradlance corrections to measured I-V characteristics:

- method A determines ellectlve array junction temperature T_J from direct temperature measurements;
- method 8 derives T_J trom data of sub-array V_{OC} recorded at dltterent Irradlance levels.

4 Equipment

4.t *Equipmant common to* me/hods A *and B:*

- a reference PV device that has been selected and calibrated in accordance with iec 904-2 or IEC 904-6;
- . a suitable means to check that the reference device and the modules are coplanar withiri ± 2' accuracy:
- voltage and current measurement Instrumentation In conformity with IEC 904·1:
- a variable load fllted to the considered power range: for low power (less than 1 kW to 2 kW) rheostats or electronic toads may be suitable: for higher power. capacitive loads are preferred:
- for a continuous tracing of the I-V curve: a tracing lable or a memory scope or any other similar equipment;
- two radiometers to check the uniformity of the In·plane radiance.

4.2 Additional equlpmanf needed for method A:

- a device, with an accuracy 01beller than ± 1 ·C lor measuring module back sur1ace lemperature:
- a commutation system which allows measuring the open-circuit voltage as well as the short-circuit current of the relerence PV devlees.

4.3 **Additional equipment** *needed for method B:*

- a device for measuring ambient air temperature with an accuracy of ± 1 °C.

5 Procedure

a) This procedure assumes clean module surfaces. If soiled surface conditions exist, appropriate action such as cleaning (if practical) and/or reporting the conditions shall be taken.

b) Verify that the environmental conditions meet the requirements of IEC 904-1, except for the following:

- voltage *and* current should be measured within 1 %;

- for measurements to be extrapolated to STC, the total in-plane irradiance must be at least 700 W . m-^{2} and the incident sun beam must be within a cone of 45° angular aperture around the module normal.

c) Using a suitable radiometer, check the **uniformity** of the in-plane irradiance over the area to be tested and select a module on which the irradiance is typical.

d) The array to be measured must be disconnected from any load such as battery and/or power conditioning equipment

e) Determine the junction temperature and the I-V characteristics by either method A or method B as described in 5.1 or 5.2.

5.1 Method A

a) Measure the temperature at the centre of the back surface at the selected central module(s). The choice of these selected modules will be based on the principles and examples indicated in figure 1.

b) calculate the mean temperature T_{SA} from all selected **modules** in the array and the difference dT between this value and the temperature of the central selected module T_{SM}:

$$dT = T_{SA} - T_{SM}$$

c) Measure the Voc of the reference PV device and determine its junction temperature T_{JRO}, by:

$$T_{JRO} = (V_{oc} - k \cdot V_{oc,STC})/\beta + 25\ °C$$

where

β is the voltage temperature coefficient of the referenced PV device. V . °C^{-1};

k is a coefficient taking into account the irradiant deviation between measurement conditions and 1 000 W . m^{-2}:

k = 1,000 for 1 000 W . m^{-2} irradiance,

k = 0,996 for 900 W . m^{-2} irradiance,

k = 0,989 for 800 W . m^{-2} irradiance,

k = 0,983 for 700 W . m^{-2} irradiance.

d) Measure the temperature T_{SR} of the back surface at the centre of the reference PV device. Measurements of T_{SR}, V_{OC} and a new measurement of T_{SM} (which is called T_{SM}') shall be made within a short period of time (i.e. within 1 min).

e) Calculate the corrected junction temperature of the module array:

$$T_O = T_{SM}' + dT + T_{JRO} - T_{SR}$$

f) Connect the variable load to the PV array. Report the point of connection.

g) If slow (manual) load scanning is used, record V_{OC} of the reference device immediately prior to the I-V scan;

h) Scan the I-V curve by varying the load such that there will be a sufficient number of points to define a smooth I-V characteristic. If slow (manual) load scanning is used (e.g. using a rheostat as load), the short-circuit current of the reference device must be determined simultaneously with each I-V point to obtain the irradiance H corresponding to that point. The total variation in radiance over the whole scan should be less than 10 %. If not, repeat 5.1 g). If a fast load scanning device such as a capacitor load (total scan time less than 0,1 s) is used, it is sufficient to record the current of the reference device at the start of the scan.

i) If slow (manual) scanning is used, remeasure the V_{OC} of the reference device. If this value differs by more than 2 % from the one obtained in 5.1 g), repeat the measurement from there.

j) Calculate the corrected junction temperature of the module array during the measurement as

$$T_1 = T_O + (T_{JR1} - T_{JRO})$$

k) Correction procedures when the reference device temperature measurements are not the same as the standard temperature for which its calibration value is given.

In this case, replace I_{SR} by I_{SRO} and I_{MR} by $I_{MR3} + \alpha_R (T_{RO} - T_3)$

where

T_{RO}	is the standard temperature of the reference device for which its calibration value is given;
T_3	is the measured temperature of the reference device;
I_{SRO}	is the short-circuit current of the reference device at the standard or other desired irradiance, and at the standard temperature T_{RO};
I_{MR3}	is the measured short-circuit current of the reference device at the measured temperature T_3;
α_R	is the current temperature coefficient of the reference device in the standard or other desired irradiance and within the temperature range of interest;

l) Extrapolate the measured I-V data to the required Acceptance Test Conditions by the method described in IEC 891. The R_S value will either be given by the supplier or determined by measurement as in IEC 891.

5.2 *Method B*

a) During the day make repeated V_{OC} array measurements, in particular at low irradiance levels (100 $W \cdot m^{-2}$ to 300 $W \cdot m^{-2}$) where no I-V scans can be performed, together with readings of ambient temperature T_A and of irradiance G (as determined from the short-circuit current of the reference device, using its calibration curve). Determine the mean value (V) and standard error of the corresponding extrapolated $V_{OC,STC}$ values for each array. The extrapolated $V_{OC,\,STC}$ values are computed using the following formula:

$$V_{OC,\,STC} = V_{OC} + N_S \times [A \times \ln\,(1\,000/H) + B \times G + \beta \times (25 - T_A)]$$

where

N_S	is the number of cells in series in the array;
A	is the product of the thermal voltage (about 25 mV/cell) and the non-ideality factor (about 1,5, so that A is about 38 mV/cell);
β	is the cell voltage temperature coefficient (ca 2,2 mV/K/cell);
B	$= \beta \times dT_J / dG$ (where dT_J / dG is about 0,03 $K/W \cdot m^{-2}$ for free-standing arrays, corresponding to NOCT of 45 °C.) In cases of special mountings, i.e. roof mounting, the coefficient B shall be determined by regression analysis (least square fit) of the V_{OC} data.

If necessary, regression analysis can be used to improve the accuracy of the other coefficients.

b) If slow (manual) load scanning is used, record V_{OC} immediately prior to the I-V scan.

c) Scan the I-V curve by varying the load such that there will be a sufficient number of points to define a smooth I-V characteristic. If slow (manual) load scanning is used (e.g. using a rheostat as load), the current output from the reference device must be determined simultaneously with each I-V point to obtain the irradiance G corresponding to that point. The total variation in irradiance over the whole scan should be less than 10 %. If not, the measurement should be repeated from 5.2 b). If a fast load scanning device such as a capacitor load (total scan time less than 0,1 s) is used, it is sufficient to record the current of the reference device at the start of the scan.

d) If slow (manual) scanning is used, compare the V_{OC} obtained at the end of the I-V scan with that measured in 5.2 b).

e) If these values differ by more than 2 %, repeat the measurement from there.

f) Calculate the corrected junction temperature of the array during the measurement as:

$$T_1 = 25 + [((V) - V_{OC})/N_S - B \times G - A \times \ln\,(1\,000/H)]/\beta$$

g) Extrapolate the measured I-V data to the required Acceptance Test Conditions by the method described in IEC 891. The R_S value will either be given by the supplier or determined by measurement as in IEC 891.

6 Accuracy

All techniques which improve accuracy should be used. At the present time it is difficult to assure an overall accuracy for the termination of the extrapolated power to better than ± 5 %.

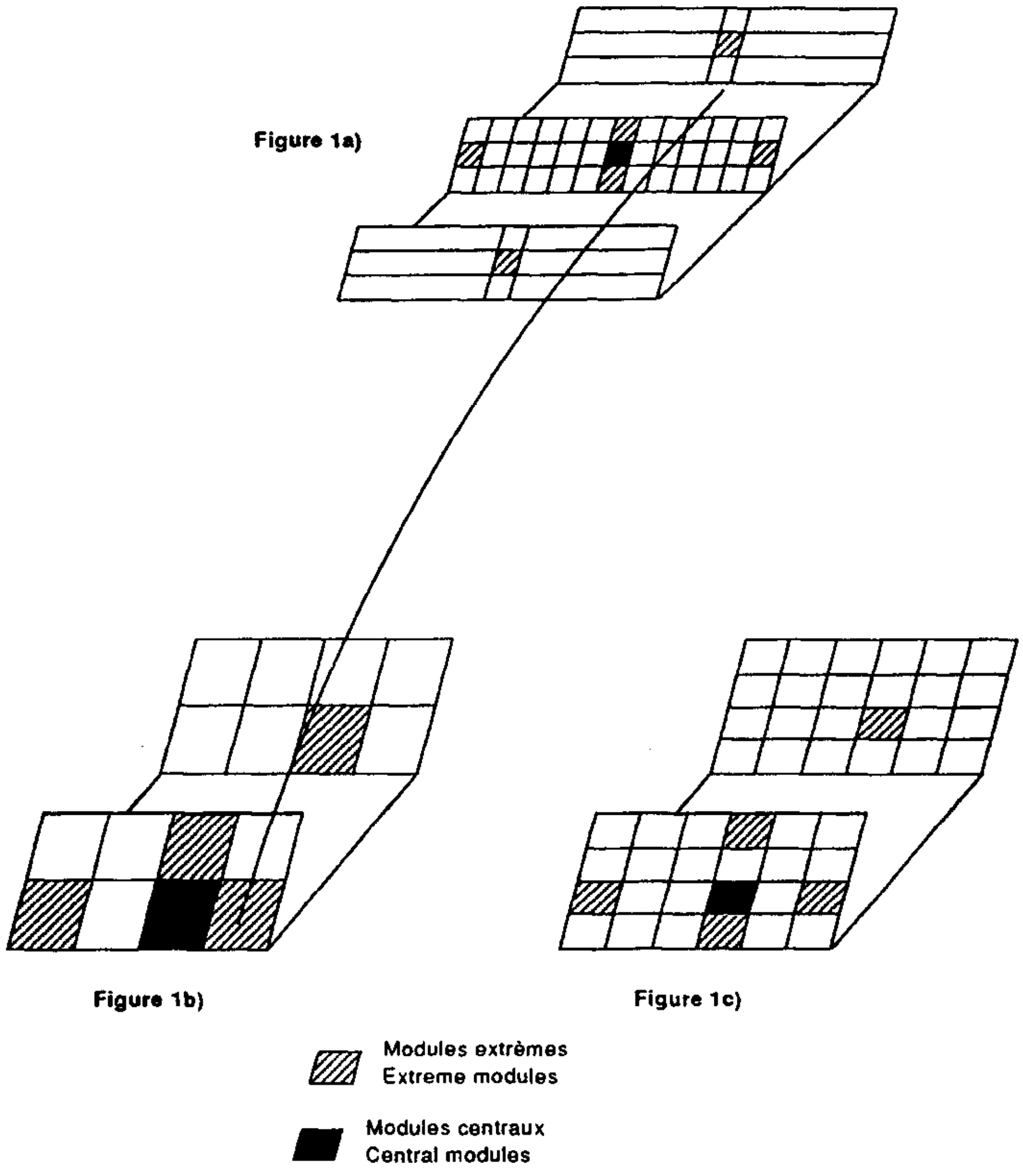

Figure 1 – Exemples de modules extrêmes et centraux
Examples of extreme and of central modules

Annex A

(informative)

Glossary

Acceptance test conditions (ATC):

Reference values of ambient temperature, in-plane irradiance and spectral distribution, specified for power rating of PV arrays.

Standard test conditions (STC):

Reference values of module temperature, in-plane irradiance and spectral distribution used for indoor (simulator) measurements:

- module temperature: 25 °C;
- in-plane irradiance: 1 000 W · m^{-2};
- spectral distribution: AM 1,5 (global);
- see IEC 904-3.

Reference device:

A reference device is a specially calibrated solar cell, multi-cell package or module which is used to measure irradiance.

For measurements in natural sunlight, when the direct solar beam is not at or near normal incidence, it is recommended to use a reference module of the same type and size as those being tested or a multi-cell package consisting of a calibrated cell surrounded by other cells (dummy or real) in such a way that frame, encapsulation system, shape, size and spacing are the same as in the modules being tested.

(*Continued from second cover*)

The technical committee has reviewed the provision of the following International Standard referred in this adopted standard and has decided that it is acceptable for use in conjunction with this standard:

International Standard	*Title*
IEC 60904-6 : 1994	Photovoltaic devices — Part 6: Requirements for reference solar modules

Only the English language text of the International Standard has been retained while adopting it in this Indian Standard, and as such the page numbers given here are not the same as in the IEC Standard.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be same as that of the specified value in this standard.

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Amendments are issued to standards as the need arises on the basis of comments. Standards are also reviewed periodically; a standard alongwith amendments is reaffirmed when such review indicates that no changes are needed; if the review indicates that changes are needed, it is taken up for revision. Users of Indian Standards should ascertain that they are in possession of the latest amendments or edition by referring to the latest issue of 'BIS Catalogue' and 'Standards: Monthly Additions'.

This Indian Standard has been developed from Doc No.: ETD 28 (6034).

Amendments Issued Since Publication

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